2.3 Microturbine/Combined Heat and Power (CHP) Technologies

The ETV Program's Greenhouse Gas Technology (GHG) Center, operated by Southern Research Institute under a cooperative agreement with EPA, has verified the performance of six microturbine systems that generate electricity at the point of use. Several of the verified technologies also include heat recovery systems that capture excess thermal energy from the system and use it to heat water and/or spaces. Systems that include this option are commonly termed combined heat and power (CHP) systems. Microturbine systems, with or without heat recovery, can reduce emissions of carbon dioxide (CO_2), methane, and pollutants including nitrogen oxides (NO_X), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM), ammonia, and total hydrocarbons (THCs). CO_2 and methane are greenhouse gases linked to global climate change. CO, SO_2, PM, ammonia, THCs, and the various compounds in the NO_X family, as well as derivatives formed when NO_X reacts in the environment, cause a wide variety of health and environmental impacts.

Available sales data indicate that a capacity of at least 7.7 megawatts (MW) of ETV-verified microturbines[18] have been installed in CHP applications in the United States in the last year. Based on the analysis in this case study, the estimated benefits of these existing installations include:

- Emissions reductions of 12,000 to 21,000 tons per year of CO_2 and approximately 70 tons per year of NO_X, with associated climate change, environmental, and human health benefits
- Reduction in emissions of other greenhouse gases and pollutants, with additional environmental and human health benefits
- Reduction in natural resource consumption by utilizing renewable fuels (such as biogas) or by increasing efficiency (and reducing net fuel consumption) when well matched to building or facility needs in a properly designed CHP application.

As market penetration increases, emission reductions and other benefits also could increase. In fact, based on the analysis in this case study and without assuming any growth from current sales levels, the ETV Program estimates the total installed capacity of ETV-verified microturbine/CHP systems could reach 46.3 MW in the next five years,[19] with the following estimated benefits:

- Emissions reductions of 70,000 to 127,000 tons per year of CO_2 and 410 to 440 tons per year of NO_X, with associated climate change, environmental, and human health benefits
- Reduction in emissions of other greenhouse gases and pollutants, with additional environmental and human health benefits

18 This estimate is based on sales from only one vendor in one year and represents 110 to 130 installations.

19 This estimate includes the 7.7 MW that the ETV Program estimates have already been installed. It represents between approximately 660 and 770 installations total. It is a conservative (low) estimate, as discussed in Appendix C.

- Additional reduction in natural resource consumption.

Other benefits of verification include the development of a well-accepted protocol that has advanced efforts to standardize protocols across programs. The Association of State Energy Research and Technology Transfer Institutions (ASERTTI), the Department of Energy (DOE), and state energy offices are adopting this protocol as a national standard protocol for field testing microturbine and CHP applications.

2.3.1 Environmental, Health, and Regulatory Background

EPA estimates that, in 2002, the United States emitted almost 6.4 billion tons of CO_2 and nearly 22 million tons of NO_X.[20] Electricity generation is the largest single source of CO_2 emissions, accounting for 39% of the total. Electricity generation also contributes significantly to NO_X emissions, accounting for 21% of the total (U.S. EPA, 2004c). A variety of other pollutants also are emitted during electricity generation, including CO, SO_2, PM, ammonia, and THCs. Each of these emissions can have significant environmental and health effects. Conventional electricity generation also consumes finite natural resources, with environmental and economic repercussions.

CO_2 is the primary greenhouse gas emitted by human activities in the United States. Its concentration in the atmosphere has increased 31% since pre-industrial times. As a greenhouse gas, CO_2 contributes to global climate change. The Intergovernmental Panel on Climate Change (IPCC) has concluded that global average surface temperature has risen 0.6 degrees centigrade in the 20th century, with the 1990s being the warmest decade on record. Sea level has risen 0.1 to 0.2 meters in the same time frame. Snow cover has decreased by about 10% and the extent and thickness of Northern Hemisphere sea ice has decreased significantly (IPCC, 2001a). Climate changes resulting from emissions of greenhouse gases, including CO_2 and methane, can have potential adverse outcomes including the following:

- More frequent or severe heat waves, storms, floods, and droughts
- Increased air pollution
- Increased geographic ranges and activity of disease-carrying animals, insects, and parasites
- Altered marine ecology
- Displacement of coastal populations
- Saltwater intrusion into coastal water supplies.

Each of these outcomes can result in increased deaths, injuries, and illnesses (U.S. EPA, 1997b). Many of these impacts, however, depend upon whether rainfall increases or decreases, which cannot be reliably projected for specific areas. Scientists currently are unable to determine which parts of the United States will become wetter or drier, but there is likely to be an overall trend toward increased precipitation and evaporation, more intense rainstorms, and drier soils (U.S. EPA, 2000d).

The various compounds in the NO_X family (including nitrogen dioxide, nitric acid, nitrous oxide, nitrates, and nitric oxide) and derivatives formed when NO_X reacts in the environment cause a wide variety of health and environmental impacts. These impacts include the following (U.S. EPA, 1998; U.S. EPA, 2003d):

- Contributing to the formation of ground-level ozone (or smog), which can trigger serious respiratory problems
- Reacting to form nitrate particles, acid aerosols, and nitrogen dioxide, which also cause respiratory problems
- Contributing to the formation of acid rain
- Contributing to nutrient overload that deteriorates water quality
- Contributing to atmospheric particles that cause respiratory and other health problems, as well as visibility impairment
- Reacting to form toxic chemicals
- Contributing to global warming.

Each of the other pollutants emitted during electricity generation also can have significant

20 Values converted from gigagrams as reported in U.S. EPA, 2004.

environmental and/or health effects. For example, SO_2 contributes to the formation of acid rain and can cause a variety of other environmental and health effects. THCs and CO can impact ground-level ozone formation, and CO can be fatal at high concentrations. PM can cause premature mortality and a variety of respiratory effects. Finally, ammonia can contribute to PM levels and result in a number of adverse heath effects.[21]

As discussed in detail in Sections 2.3.2 and 2.3.3, distributed generation technologies have the potential to reduce emissions of CO_2, NO_X, and other greenhouse gases and pollutants (e.g., CO, methane from biogas, SO_2, PM, ammonia, and THCs), as well as conserve finite natural resources and utilize resources that would otherwise be wasted (e.g., biogas, landfill gas, and oilfield flare gas). In recognition of these benefits, EPA has established programs like the CHP Partnership to encourage the use of CHP technologies, including those that use microturbines. The CHP Partnership is a voluntary EPA-industry effort designed to foster cost-effective CHP projects. The goal of the partnership is to reduce the environmental impact of energy generation and build a cooperative relationship among EPA, the CHP industry, state and local governments, and other stakeholders to expand the use of CHP (U.S. EPA, 2005e).

In a related effort, EPA and many states are developing and using output-based regulations for power generators. Output-based regulations establish emissions limits on the basis of units of emissions per unit of useful power output, rather than on the traditional basis of units of emissions per unit of fuel input. The traditional, input-based approach relies on the use of emissions control devices, whereas output-based regulations encourage energy efficiency. Currently a number of states, including Connecticut and Massachusetts, have developed output-based regulations that recognize the energy efficiency benefits of CHP projects. Regulated sources can use technologies like the ETV-verified microturbine/CHP systems as part of their emissions control strategy to comply with these regulations. EPA also has developed resources, such as Output-Based Regulations: A Handbook for Air Regulators (U.S. EPA, 2004d), to assist in developing output-based regulations for power generators (U.S. EPA, 2005f).

> "By installing a CHP system designed to meet the thermal and electrical base loads of a facility, CHP can increase operational efficiency and decrease energy costs, while reducing emissions of greenhouse gases that contribute to the risks of climate change." *—EPA's CHP Partnership Web site (U.S. EPA, 2005e)*

2.3.2 Technology Description

"Large- and medium-scale gas-fired turbines have been used to generate electricity since the 1950s, but recent developments have enabled the introduction of much smaller turbines, known as microturbine/CHP systems" (U.S. EPA, 2002h). Microturbines are well suited to providing electricity at the point of use because of their small size, flexibility in connection methods, ability to be arrayed in parallel to serve larger loads, ability to provide reliable energy, and low-

A typical microturbine CHP installation (Capstone 60 microturbine and Unifin Heat Exchanger)

21 Please note that this paragraph is meant as an overview only. It does not represent a comprehensive list of the pollutants emitted during electricity generation or their environmental and health effects. For discussion of the health and environmental effects of CO and PM, see Section 2.1.1. For discussion of the health and environmental effects of ammonia, see Section 2.6.2.

emissions profile (NREL, 2003). By generating electricity at the point of use, microturbines reduce the need to generate electricity from sources such as large electric utility plants. When coupled with heat recovery systems that capture excess thermal energy to heat water and/or spaces, microturbines also reduce the need to use conventional heating technologies such as boilers and furnaces, which emit significant quantities of CO_2, NO_X, and CO. When well matched to building or facility needs in a properly designed CHP application, microturbines can increase operational efficiency and avoid power transmission losses, thereby reducing overall emissions and net fuel consumption. Microturbines also can be designed to operate using biogas from sources including animal waste, wastewater treatment plants, and landfills. Biogas is a renewable resource that would otherwise go unused because it is traditionally flared or vented to the atmosphere.

Because they are a relatively new technology, reliable performance data are needed on microturbine/CHP technologies. The ETV Program responded to this need by verifying the performance of six microturbine technologies (see Exhibit 2.3-1), four of which include heat recovery. Residential, commercial, institutional, and industrial facilities were used as test sites. One of the technologies tested operated on biogas recovered from animal waste.

During each test, the ETV Program verified heat and power production performance, power quality performance, and emissions performance. Heat and power production performance tests measured electrical power output and electrical efficiency at selected loads. For systems with heat recovery, these tests also measured heat recovery rate, thermal efficiency, and total system efficiency at selected loads. At full load under normal operations, verified electrical efficiencies ranged from 20.4% to 26.2%. For systems with heat recovery, verified thermal efficiencies at full load and normal operation ranged from 7.2% to 47.2%. For these systems, verified total system efficiencies ranged from 33.4% to 71.8%.[22] In tests at less than full load, electrical efficiencies were lower, but thermal efficiencies were higher. In tests with enhanced heat recovery (as opposed to normal operations), thermal and total efficiencies were higher.

Exhibit 2.3-1

ETV-Verified Microturbine and CHP Technologies

Technology Name	Electricity Generating Capacity (kilowatts [kW])	Includes Heat Recovery for CHP?	Additional Information
Mariah Energy Corporation Heat PlusPower™ System	30	Yes	Tested at a 12-unit condominium site that combines a street-level retail or office space with basement, and a one- or two-level residence above.
Ingersoll-Rand Energy Systems IR PowerWorksTM 70 kW Microturbine System	70	Yes	Tested at a 60,000 square-foot skilled nursing facility providing care for approximately 120 residents.
Honeywell Power Systems, Inc. Parallon® 75 kW Turbogenerator	75	No	Tested at a 55,000 square-foot university office building.
Honeywell Power Systems, Inc. Parallon® 75 kW Turbogenerator With CO Emissions Control	75	No	Same technology as above, but with installation of optional CO emissions control equipment.
Capstone 30 kW Microturbine System	30	Yes	Tested system operates on biogas recovered from animal waste generated at a swine farm.
Capstone 60 kW Microturbine CHP System	60	Yes	Tested at a 57,000 square-foot commercial supermarket.

Sources: Southern Research Institute, 2001a, 2001b, 2001c, 2003a, 2003b, 2004.
Note: The two verified Honeywell products are no longer sold.

22 Note that the lower end of the range for thermal and total efficiency represents a site where efficiencies under "normal operating conditions" were low because of low space heating and dehumidification demand during testing. Excluding this site, the range of thermal efficiencies was 21% to 47.2% and the range of total efficiencies was 46.3% to 71.8%.

Power quality performance tests measured electrical frequency, voltage output, power factor, and voltage and current total harmonic distortion (THD). The ETV Program found that all of the technologies maintained continuous synchronization with the utility grid throughout the corresponding test periods. Verified average electrical frequencies ranged from 59.999 to 60.001 hertz (Hz). Verified average voltage outputs ranged from 215.21 to 494.75 volts. For all technologies, the power factor remained relatively constant, and ranged from 62.7% to 99.98%. In all but one of the tests, voltage and current THD were below the threshold specified in the Institute of Electrical and Electronics Engineers (IEEE) guidelines.

Emissions performance tests measured emissions concentrations and rates at selected loads. Verified CO_2 emissions rates ranged from 1.34 to 3.90 pounds per kilowatt-hour (lbs/kWh). Verified NO_X emissions rates ranged from 4.67×10^{-5} to 4.48×10^{-3} lbs/kWh. The ETV Program also verified concentrations and emissions rates for other pollutants and greenhouse gases, including CO and THCs, and, for some of the technologies, methane, sulfate, total recoverable sulfur, total particulate matter, and ammonia. Three of the verification reports also estimated total CO_2 reductions compared to emissions generated by electricity obtained from the grid and heat obtained from a conventional technology, either for the test sites or for hypothetical sites. In two cases, total NO_X reductions were estimated in a similar manner. These estimates are presented in detail in Appendix C. More detailed performance data are available in the verification reports for each of the technologies (Southern Research Institute, 2001a, 2001b, 2001c, 2003a, 2003b, 2004).

2.3.3 Outcomes

Microturbine/CHP systems can be used at residential, commercial, institutional, and industrial facilities to provide electricity at the point of use and reduce the need to use conventional heating technologies. As discussed below under "Technology Acceptance and Use Outcomes," based on data from one vendor, at least 7.7 MW of ETV-verified microturbines have been installed for CHP applications in the United States in the last year. Because this estimate includes sales from only one vendor during the last year, it likely is conservative (low) and represents the minimum market penetration.

The ETV Program used the estimate of current market penetration to estimate the capacity of ETV-verified microturbine/CHP systems that could be installed in the near future. Specifically, ETV estimated that 38.6 MW could be installed in the next five years, for a total installed capacity, including the current minimum penetration, of 46.3 MW, as shown in Exhibit 2.3-2. Appendix C explains the derivation of this estimate of future market penetration.[23] The ETV Program used the current minimum and future market penetration scenarios to estimate the emissions reduction outcomes shown below.

Exhibit 2.3-2

Capacity of ETV-Verified Microturbine/CHP Systems Potentially Installed

Market Penetration	Total Capacity (MW)
Current Minimum	7.7
Future Penetration	46.3

Values rounded to nearest 0.1 MW

Emissions Reduction Outcomes

Emissions reductions from the application of microturbine/CHP technology depend on a number of factors, including the electricity and heating demand of the specific application, the microturbine emissions rates, and the emissions rates of the conventional source that the microturbine replaces, such as an electric utility power plant or hot water heater. These factors vary geographically and by specific application. Given this variation, quantitative data are not available to characterize these factors for every potential ETV-verified microturbine/CHP application. Therefore, this analysis uses model facilities developed by Southern Research Institute for the test sites to estimate emissions reductions for

23 As discussed in Appendix C, this is a conservative (low) estimate.

each market penetration scenario. Appendix C describes the model sites and the methodology for using the model facilities to estimate nationwide emissions reductions for the microturbine capacities shown in Exhibit 2.3-2. Exhibit 2.3-3 shows upper- and lower-bound estimates of annual CO_2 and NO_X reductions generated using this methodology for each market penetration scenario. The upper-bound estimates assume each ETV-verified microturbine/CHP application is represented by the model site that achieves the greatest reduction for that compound. The lower-bound estimates assume each ETV-verified microturbine/CHP application is represented by the model site that achieves the lowest reduction for that compound.

In addition to the CO_2 and NO_X reductions shown in Exhibit 2.3-3, the ETV-verified microturbine/CHP systems also have the potential to reduce emissions of other greenhouse gases, such as methane, and other pollutants, such as THCs. Quantitative data are not available, however, to estimate these reductions. Quantitative data also are not available to estimate the environmental and health outcomes associated with the reductions in CO_2, NO_X, or other emissions. As discussed in Section 2.3.1, however, the environmental and health effects of these emissions are significant. Therefore, the benefits of reducing these emissions also could be significant.

Resource Conservation, Economic, and Financial Outcomes

Section 2.3.2 reports the verified efficiencies of the ETV-verified microturbine technologies. In general, these efficiencies compare favorably with those of separate heat and grid power applications, particularly when coupled with heat recovery in CHP applications. In addition, because they generate and use electricity onsite, microturbines avoid losses associated with the transmission of electricity, which can be in the range of 4.7 to 7.8% (Southern Research Institute, 2001a, 2001b, 2003a). Also, as shown in one of the verification tests, microturbines can be fueled by biogas, a renewable resource. Therefore, the application of the ETV-verified microturbine/CHP systems can result in the conservation of finite natural resources and potentially result in cost savings for the user due to efficiency increases and the use of renewable or waste fuels rather than conventional fuels. Quantitative data are not available to estimate these resource conservation outcomes or associated cost savings, although at least one vendor reports significant sales of their ETV-verified biogas-fueled technology in the last year (see “Technology Acceptance and Use Outcomes”).

Exhibit 2.3-3

Estimated Potential Emissions Reductions for ETV-Verified Microturbine/CHP Systems[24]

Market Penetration	Annual Pollutant Reduction: CO_2 (tons per year) (1)	Annual Pollutant Reduction: NO_X (tons per year) (2)
Upper Bound		
Current Minimum	21,000	70
Future Penetration	127,000	440
Lower Bound		
Current Minimum	12,000	70
Future Penetration	70,000	410

(1) Rounded to nearest 1,000

(2) Rounded to nearest 10

24 Reductions vary based on the source for grid power or thermal supply (hydroelectric, coal, etc.).

Technology Acceptance and Use Outcomes

According to recent reports, one verified vendor sold more than 16.5 MW of ETV-verified microturbines in the last year. Of these sales, approximately 7.7 MW were for CHP applications in the United States.[25] Also, 11% of last year's sales were for resource recovery applications, many of which used the ETV-verified biogas-fueled technology. This vendor projects increasing sales of ETV-verified microturbines during each of the next several years (ETV Vendor, 2005). Vendors also report that ETV verification has increased awareness of this technology, resulting in marketing opportunities (see quotes at right).

Scientific Advancement Outcomes

Other benefits of verification include the development of a well-accepted protocol that has advanced efforts to standardize protocols across programs. This protocol (i.e., the "Generic Field Testing Protocol for Microturbine and Engine CHP Applications") was originally developed by Southern Research Institute for ASERTTI and was eventually adopted by the GHG Center and published as an ETV Generic Verification Protocol. The protocol also is scheduled to be adopted by ASERTTI, DOE, and state energy offices as a national standard protocol for field testing.

"People are skeptical of new technology, which is why Mariah Energy needed believable third-party verification. It may be years before we know the impact ETV had on sales, but it is already an important factor in discussions with our new customers, and ETV has opened doors we didn't anticipate it would. For example, new partnering organizations are using ETV data to make decisions on investing in our technology. Also, new opportunities to conduct field demonstrations have occurred, and we've been invited to testify at Senate hearings on clean high performance energy technology." *—Paul Liddy, President and CEO of Mariah Energy (U.S. EPA, 2002h)*

"We are very proud of our ETV results. We cite them all the time, in fact most recently in our press release last week." *—Keith Field, Director of Communications, Capstone Turbine Corporation (Field, 2005)*

Acronyms used in this case study:

ASERTTI	Association of State Energy Research and Technology Transfer Institutions	kW	kilowatts
CHP	combined heat and power	lbs/kWh	pounds per kilowatt-hour
CO	carbon monoxide	MW	megawatts
CO_2	carbon dioxide	NO_X	nitrogen oxides
DOE	Department of Energy	PM	particulate matter
GHG Center	ETV's Greenhouse Gas Technology Center	SO_2	sulfur dioxide
Hz	hertz	THCs	total hydrocarbons
IEEE	Institute of Electrical and Electronics Engineers	THD	total harmonic distortion
IPCC	Intergovernmental Panel on Climate Change		

25 See Appendix C for detailed derivation of this estimate.